Constellation-X

Requirements Flowdown

(DRAFT)

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1. INTRODUCTION

The Constellation-X project includes the definition, design, development, verification, operation of and data analysis from a set of free-flying X-ray satellites to be designated as the Constellation-X Mission.

Top level program requirements have been established (see Constellation-X Top Level Requirements, Version 7/20/00). This document identifies the lower level requirements on the many subsystems of Constellation-X. These lower level requirements have been derived from the top level requirements, either directly or indirectly via error budgets and analyses.

This document will be updated and distributed as required. As the top level requirements change, this document will be reviewed, edited and updated so as to track the top level requirements.

2. FLIGHT SEGMENT

The Constellation-X flight segment is comprised of four individual satellites having a common design. Each satellite carries three X-ray telescopes and the necessary spacecraft subsystems. The four satellites working together must meet the top level mission requirements.

Each of the four Constellation-X satellites which make up the flight segment are nominally identical. The requirements for each satellite are grouped into two categories; telescope and spacecraft. The requirements presented below are derived from the Constellation-X top level mission requirements, either directly via flowdowns or budgets, or indirectly via studies.

2.1 Telescope Requirements

To meet top level mission requirements each Constellation-X satellite will carry three different types of X-ray telescopes:

1. Spectroscopy X-ray Telescope (SXT)/Grating/ Charge Coupled Device(CCD)
2. SXT/Calorimeter
3. Hard X-ray Telescope (HXT)

The first two telescopes listed above (SXT/Grating/CCD and SXT/Calorimeter) share the same optics assembly, the Spectroscopy X-ray Telescope Optics Assembly, while the third (HXT) has its own optics. In the case of the HXT, each satellite may carry several optics sub-assemblies and detector sub-assemblies plus a detector electronics unit. In this specification the combination of all HXT optics, detectors and electronics units carried by one of the four satellites ~~are~~ is considered to be an HXT telescope. The top level mission requirements are met by combining the three different types of X-ray telescopes, with each telescope designed to cover (with overlap) different energy bands. The SXT/Grating/CCD telescope has high resolving power at the lower end of the mission band pass, which is 0.25 to 40.0 keV. Its resolving power increases as the energy decreases (or wavelength increases). The SXT/Calorimeter telescope also has area over the SXT ~~soft~~ x-ray band. Its resolving power, however, increases with energy. The HXT covers the higher end of the mission energy band. The requirements pertaining to each of the three telescopes are given in the following sections.

2.1.1 SXT/Grating/CCD

2.1.1.1 Band Pass

The SXT/Grating/CCD telescope shall cover the energy range from 0.25 keV (49.596 angstroms) to 2.0 keV (6.200 angstroms).

(source – Top Level Requirement 3.1 Band Pass and Areas flowdown)

2.1.1.2 Spectral Resolution

The SXT/Grating/CCD telescope shall meet the requirements specified in Table 1 for wavelength resolution in the first three grating orders, for on-axis sources.

Grating Order	Minimum Wavelength – A^0 (Max Energy- Ref)	Maximum Wavelength – A^0 (Min Energy- Ref)	Required Wavelength Resolution (FWHM) A^0
-1	6.20 (2.0 keV)	50.00 (0.25 keV)	0.0500
-2	6.20 (2.0 keV)	20.00 (0.62 keV)	0.0250
-3	6.20 (2.0 keV)	15.00 (0.82 keV)	0.0125

Table 1 – SXT/Grating/CCD Spectral Resolution

(This information may end up in a derivation document)

The resolution of a reflection grating and readout are naturally specified in terms of wavelength, in our case the Full Width Half Maximum (FWHM) value of an X-ray line as readout by the CCD detector. This quantity is approximately constant, for each grating order, over the bandpass of the Grating/CCD telescope, the resolution being mainly determined by the optic Angular resolution. The relationship between resolving power ($R = \lambda/\Delta\lambda$) and wavelength resolution ($\Delta\lambda$) is illustrated in Figure 1. Given the specified resolutions as listed in Table 1, the resolving power for each order is shown in the lower pane of the plot. The higher orders have better resolution and resolving power, but over a more limited bandpass. The complete Grating/CCD bandpass is required in first order, and this sets the physical length and placement of the CCD readout in the dispersion direction. In the top pane of Figure 1, the dispersions (in mm, vs. wavelength) of the three grating orders are shown, as well as the fixed dispersion of the 0^{th} order. With the CCD readout limits as shown (~475mm – 910mm) the more limited wavelength ranges as specified in Table 1 apply, since the longer wavelengths are not physically on the detector for the -2 and –3 orders. In addition to the limited wavelength ranges shown in Figure 1, we also see that the resolving power of the 1^{st} and 2^{nd} orders falls below the top level specification of 300 at the shorter wavelengths (higher energies). The reason for keeping the 1^{st} and 2^{nd} order resolution specifications for wavelength bands in which their resolving power is less than 300 is for cross-calibration with the Calorimeter (the shorter wavelengths, or higher energies, are where the overlap between the two instruments occurs).

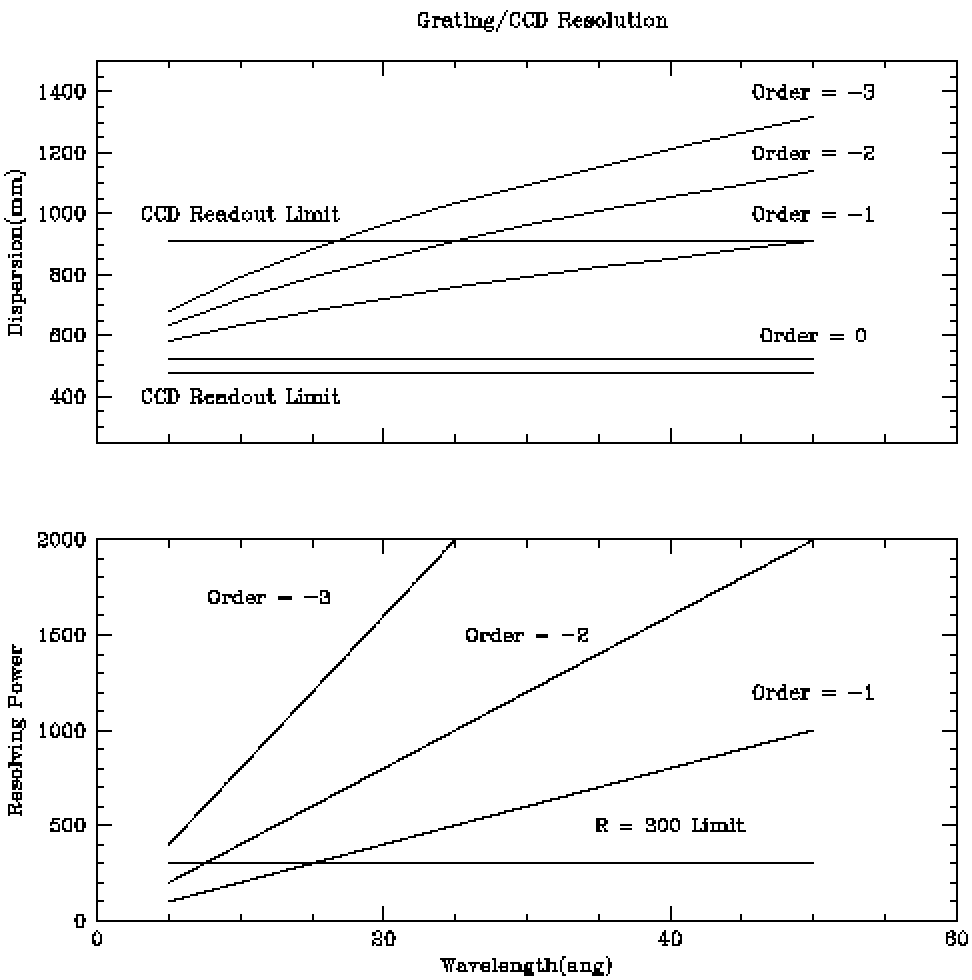


Figure 1 – Grating/CCD Resolution

(source – top level requirement 3.2 – spectral resolution and Areas flowdown, plus need to cross-calibration with calorimeter)

2.1.1.3 Spectral Accuracy

The SXT/Grating/CCD telescope shall have an absolute wavelength scale accuracy of < 20% of its **achieved** wavelength resolution.

(source – top level requirement 3.3 – Spectral Accuracy plus cross-calibration)

2.1.1.4 Effective Area

E(keV)	Line	SXT/Grating/CCD	SXT/Calorimeter	Sum of SXT	HXT
0.277	C-Ka	250	0	250	0
0.523	O-Ka	250	0	250	0
1.253	Mg-Ka	750	3000	3750	0
1.497	Al-KA	750	3000	3750	0
4.510	Ti-Ka	0	2000	2000	0
6.403	Fe-Ka	0	1500	1500	375
8.048	Cu-Ka	0	1000	1000	375
9.713	Au-La	0	500	500	375
17.497	Mo-Ka	0	0	0	375
22.163	Ag-Ka	0	0	0	375
33.441	La-Ka	0	0	0	375
41.542	Eu-Ka	0	0	0	375

Table 2 – Per Satellite Telescope Effective Area Specifications,

Assuming Four Satellites

The required on-axis effective areas **(per satellite, assuming four satellites)** for each of the three telescopes carried on each of four satellites are listed in Table 2. For the SXT/Grating/CCD telescope, the specified area is the sum of areas for grating orders –1, -2 and –3 for which the resolving power (R) is greater than 300. The required area is the area after accounting for loss factors due to mirror structure, mirror reflectivity, contamination effects, detector quantum efficiency**,** filter transmission, etc. The effective area for off-axis sources within the specified field-of-view shall be at least TBD% of the area for an on-axis source. Table 2 gives the required area at a number of energies and a relevant X-ray line, for testing purposes, if one exists at the specified energy.

(source – top level requirement 3.4 – mission effective areas and Areas flowdown)

2.1.1.5 Photometric Accuracy

2.1.1.5.1 Absolute Fluxes

During normal science operations, the absolute flux of an on-axis source (source within the central ±TBD arc-minutes of the detector FOV) at any energy within the SXT/Grating/CCD telescope band pass shall be determined to within an accuracy of 10% or better. (We want to know the photons/cm^2/sec for the observed source. We get a count rate in photons/sec from the observation, so therefore we need to know the effective area of the telescope in cm^2 (mirror and optical train) to an absolute accuracy of 10%, including modeling uncertainties. This is done by ground calibration, modeling and on-orbit calibration).
(source – top level requirements)

2.1.1.5.2 Relative Fluxes

During normal science operations, the relative fluxes from an on-axis source (source within the central ±TBD arc-minutes of the detector FOV) over any set of energies within the SXT/Grating/CCD telescope band pass shall be determined to within an accuracy of 5% or better. (The absolute fluxes may be in error, but their ratios should be accurate to 5% or better).

(source – top level requirements)

2.1.1.5.3 Off-Axis Response

The additional absolute and relative flux determination errors due to off-axis (source outside the central ±TBD arc-minutes of the detector FOV) source locations shall be no more than 1%, giving an absolute flux accuracy requirement of 11% and a relative flux requirement of 6% for off-axis sources.
(source – top level requirements)

2.1.1.6 Angular Resolution

Not applicable.

2.1.1.7 Field of View

The SXT/Grating/CCD telescope field of view shall be at least 2.5 arc-minutes, i.e., a point source located within ±1.25 arc-minutes of the **SXT/Calorimeter** aim point shall be observable with full performance by the SXT/Grating/CCD.

(This is a derived requirement. We will design the satellite so as to point the boresight of the SXT/Calorimeter; the SXT/Grating/CCD and HXT must be aligned to it)

2.1.1.8 Extended Source Capability

Not applicable

2.1.1.9 Bright Source Capability

2.1.1.9.1 Point Source

Point sources with overall per satellite count rates of up to TBD counts per second over the SXT/Grating/CCD band shall be observable in the SXT/Grating/CCD without degradation of spectral resolution.

(source – top level requirements/instrument capabilities)

2.1.1.9.2 Extended Source

Not applicable.

2.1.1.10 Timing Accuracy and Resolution

The SXT/Grating/CCD shall time tag each CCD frame to an accuracy of 1msec relative to a timing signal distributed from the spacecraft to the telescope electronics.

(source – TBD)

2.1.1.11 Radiation

The SXT/Grating/CCD telescope components shall be designed to meet performance specifications over the mission lifetime for the expected radiation environment. The SXT/Grating/CCD telescope shall be capable of determining the effects of the radiation on their performance and performance degradation and calibrating for these effects.

(source – top level requirements)

2.1.2 SXT/Calorimeter

2.1.2.1 Band Pass

The SXT/Calorimeter telescope shall cover the energy range from 0.3 keV to 10.0 keV.

(source – top level requirements 3.1, Areas Flowdown and cross-calibration)

2.1.2.2 Spectral Resolution

The SXT/Calorimeter telescope have energy resolution as specified in Table 3 below.

Energy Band (keV)	**Spectral Resolution ΔE(eV)**
0.300 – 0.600	2.0
0.600 – 7.000	2.0
7.000 – 8.000	2.3
8.000 – 10.000	3.0

Table 3 - SXT/Calorimeter Spectral Resolution

(source – top level requirement 3.2 – spectral resolution, need to cross-calibrate with the SXT/Grating/CCD)

2.1.2.3 Spectral Accuracy

The spectral accuracy of the SXT/Calorimeter telescope shall 20% of the achieved spectral resolution.

(source – revised top level requirement 3.3 – spectral accuracy)

2.1.2.4 Effective Area

The required on-axis effective area for each of the four the SXT/Calorimeter telescopes is listed in Table 2 above. These areas are with R > 300. The required area is the area after loss factors for mirror structure, mirror reflectivity, contamination effects, detector quantum efficiency and filter transmission are taken into account. The effective area for off-axis sources within the specified field-of-view shall be at least TBD% of the area for an on-axis source.

(source – top level requirement 3.4 – mission effective areas, Areas flowdown and new cross-calibration top level spec)

2.1.2.5 Photometric Accuracy

2.1.2.5.1 Absolute Fluxes

During normal science operations for sources with count rates of TBD or less, the absolute flux of an on-axis source at any energy within the SXT/Calorimeter telescope band pass shall be determined to within an accuracy of 10% or better.

(source – top level requirements)

2.1.2.5.2 Relative Fluxes

During normal science operations, the relative fluxes from an on-axis source over any set of energies within the SXT/Calorimeter telescope band pass shall be determined to within an accuracy of 5% or better.

(source – top level requirements)

2.1.2.5.3 Off-Axis Response

The additional absolute and relative flux determination errors due to off-axis source locations shall be no more than 1%, giving an absolute flux accuracy requirement of 11% and a relative flux requirement of 6% for off-axis sources.

(source – top level requirements)

2.1.2.6 Angular Resolution

The Angular resolution of the SXT/Calorimeter telescope shall be 15 arc-seconds (HPD) over the specified band pass.

(source – top level requirement 3.6)

2.1.2.7 Field of View

The SXT/Calorimeter telescope non-vignetted on-axis field of view shall be at least 2.5 arc-minutes (square), with effective area as specified above.

(source – top level requirements)

2.1.2.8 Extended Source Capability

The SXT/Calorimeter telescope shall be capable of obtaining spectra with the required Angular and spectral resolutions over the required energy range for sources that are larger in extent than the SXT/Calorimeter field of view (done by combining observations, each with a small target offset from the other).

(source – top level requirements)

2.1.2.9 Bright Source Capability

2.1.2.9.1 Point Source

Point sources with overall per satellite count rates of up to 10,000 counts per second over the SXT/Calorimeter band shall be observable in the SXT/Calorimeter without degradation of spectral resolution or timing precision. For count rates above 10,000 (TBR), timing precision shall not be degraded, but some spectral resolution degradation will be permitted.

(source – top level requirements)

2.1.2.9.2 Extended Source

Extended sources which fill the SXT/Calorimeter field of view and produce SXT/Calorimeter per satellite count rates of 10,000 over the SXT/Calorimeter band pass shall be observable without degradation of spectral resolution or timing precision.

(source – top level requirements)

2.1.2.10 Radiation

The SXT/Calorimeter telescope shall be designed to operate for the mission lifetime within the expected radiation environment. The SXT/Calorimeter telescope shall be capable of determining the effects of the radiation on their performance and performance degradation and calibrating for these effects.

(source – top level requirements)

2.1.2.11 Timing Accuracy and Resolution

The SXT/Calorimeter shall time tag each photon event to an accuracy of 10μsec relative to a timing signal sent from the spacecraft to the telescope electronics.

(source – timing error budget)

2.1.3 HXT

2.1.3.1 Band Pass

The HXT telescope shall cover the energy band from 6.0 keV to 40.0 keV.

(source – Top Level Requirements 3.1 Band Pass Areas flowdown and cross-calibration requirement)

2.1.3.2 Spectral Resolution

The HXT shall have energy resolution ($\Delta E/E$) of 10% (or better) over the entire HXT band pass.

(source - Top level requirement 3.2)

2.1.3.3 Spectral Accuracy

The spectral accuracy of the HXT shall be TBD% (or better) of the achieved energy resolution over the HXT energy band (i.e., determination of the absolute energy of a line to TBD%)

(source – top level requirement 3.3)

2.1.3.4 Effective Area

The required on-axis effective area for each of the four the HXT telescopes is listed in Table 2, above. The required area is the area after loss factors for mirror structure, mirror reflectivity, contamination effects, detector quantum efficiency and filter transmission are taken into account. The effective area for off-axis sources within the specified field-of-view shall be at least TBD% of the area for an on-axis source.

(source – top level requirement 3.4 and cross-calibration)

2.1.3.5 Photometric Accuracy

2.1.3.5.1 Absolute Fluxes

During normal science operations, the absolute flux of an on-axis source at any energy within the HXT band pass shall be determined to within an accuracy of 10% or better.

(source – top level requirements)

2.1.3.5.2 Relative Fluxes

During normal science operations, the relative fluxes from an on-axis source over any set of energies within the HXT band pass shall be determined to within an accuracy of 5% or better.

(source – top level requirements)

2.1.3.5.3 Off-Axis Response

The additional absolute and relative flux determination errors due to off-axis source locations shall be no more than 1%, thus increasing the requirements for the accuracy of the absolute flux to 11% for the relative fluxes to 6% for off-axis sources.

(source – top level requirements)

2.1.3.6 Angular Resolution

The HXT shall have angular resolution of 1 arc-minute (HPD) or better over its energy band.

(source – top level requirement 3.6)

2.1.3.7 Field of View

The HXT shall have a minimum non-vignetted on-axis field of view of 8 arc-minutes.

(source – top level requirements 3.7)

2.1.3.8 Extended Source Capability

The HXT telescope shall be capable of obtaining spectra with the required Angular and spectral resolutions over the required energy range for sources that are larger in extent than the HXT Angular resolution.

(source – top level requirements 3.9)

2.1.3.9 Bright Source Capability

2.1.3.9.1 Point Source

TBD

(source – top level requirements)

2.1.3.9.2 Extended Source

TBD

(source – top level requirements)

2.1.3.10 Radiation

The HXT telescope components shall be designed to operate for the mission lifetime within the expected radiation environment. The HXT telescope shall be capable of determining the effects of the radiation on their performance and performance degradation and calibrating for them.

(source – top level requirement 3.11)

2.1.3.11 Timing Precision and Resolution

The HXT shall time tag each photon event to a precision of 10μsec relative to a timing signal distributed from the spacecraft to the telescope electronics.

(source – timing error budget)

2.1.4 Telescope Cross-Calibration Requirements

Need to determine relative flux to within 5% of the CCD/grating, too. How do we spec that?

According to the top level requirements, the relative flux between SXT/Grating/CCD and calorimeter (anything in 0.25 to 10 keV band) must also be 5%. How do we flow that down? FROM CROSS-CALIBRATION RQMTS!!!!!!!!

2.1.5 Telescope Component Requirements

2.1.5.1 SXT Optics Assembly

The SXT optics assembly is a multi-shell X-ray mirror assembly which also provides an interface and mounting structure for the Reflection Grating Assembly (RGA). The RGA is mounted aft (towards the focal plane) of the SXT optics assembly. The SXT optics assembly also includes thermal pre and post-collimators and thermal control hardware, alignment aids and the mounting interface to the satellite.

2.1.5.1.1 Optical Design

The SXT is a Wolter type I design with multiple mirror pairs, each pair consisting of a paraboloid and a hyperboloid optic. The design provides for an interface to the RGA, which nominally covers the outer annulus of the optic.

2.1.5.1.2 Focal Length

The SXT shall have a nominal focal length of 10.0m.

2.1.5.1.3 Field of View

The SXT optics assembly shall provide a non-vignetted on-axis field of view (diameter) of at least 2.5 (TBR) arc-minutes.

2.1.5.1.4 Effective Area

The requirements for effective area each of the four (one per satellite) SXT optics are presented in the table below.

E(keV)	**Grating Area(cm^2)** **Outer Mirror Pairs**	**Non-Grating Area (cm^2)** **Inner Mirror Pairs**	**Total Area(cm^2)** **All Mirror Pairs**
0.277	5550	2320	7870
0.523	5240	2250	7490
1.253	5240	2260	7500
1.497	5160	2250	7410
4.510	1540	1690	3230
6.403	280	1630	1910
8.048	10	1200	1210
9.713	0	760	760

Table 4 – SXT Optics Effective Area

2.1.5.1.5 Angular Resolution

The angular resolution of the SXT optics assembly shall be 13 arcseconds (HPD) over the required bandpass. This value for angular resolution includes, but is not limited to, the following error sources:

1. Mirror fabrication, assembly and alignment
2. Short term orbital variations
3. long term on-orbit variations

(source – SXT Angular resolution error budget)

2.1.5.1.6 Mass

The mass of the SXT optics assembly shall not exceed 680 kgm. This mass includes optics, structure, collimators, mounting flange, cables, insulation, baffles and thermal control hardware but excludes the reflection grating assembly (which is mounted as an integral part of the SXToptics assembly).

2.1.5.1.7 Envelope

The envelope of the SXT optics assembly is shown in Figure 1.

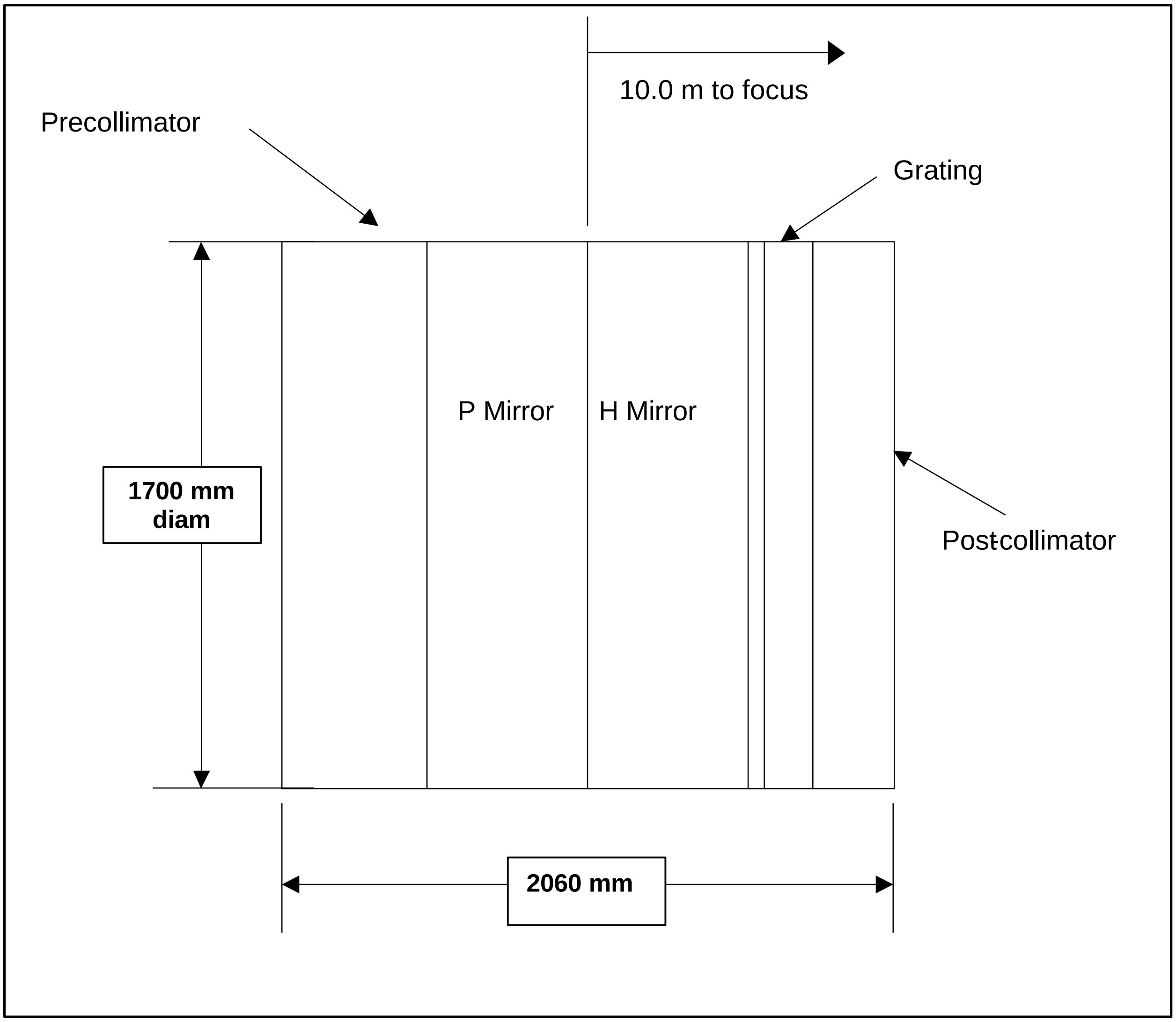


Figure 2 – SXT Optics Assembly Envelope

2.1.5.1.8 Power

The SXT shall require no more that TBD watts for thermal control.

2.1.5.1.9 Interfaces

TBD.

2.1.5.2 Reflection Grating Assembly

The Reflection Grating Assembly (RGA) is an array of thin reflection gratings mounted at grazing incidence to the X-ray beam coming out of the SXT. In the Constellation-X design, the grating array covers an outer annulus of the SXT, and it intercepts a large fraction (but not all) of the X-ray light which passes out of the SXT into the RGA.

2.1.5.2.1 Envelope and Geometry

The Constellation-X reflection grating assembly will be integrated into the Spectroscopy X-Ray Telescope (SXT) mirror assembly. The location of the grating assembly is shown in Figure 2. It is located aft (towards the focal plane) of the P and H mirrors and the mirror structure, but forward of the mirror module post-collimator. A 250mm axial space is allocated for the RGA. The inner and outer radii of the allowed annular envelope are 460mm and 850mm. The distance from the axial center of the grating to the focal plane is 9315mm.

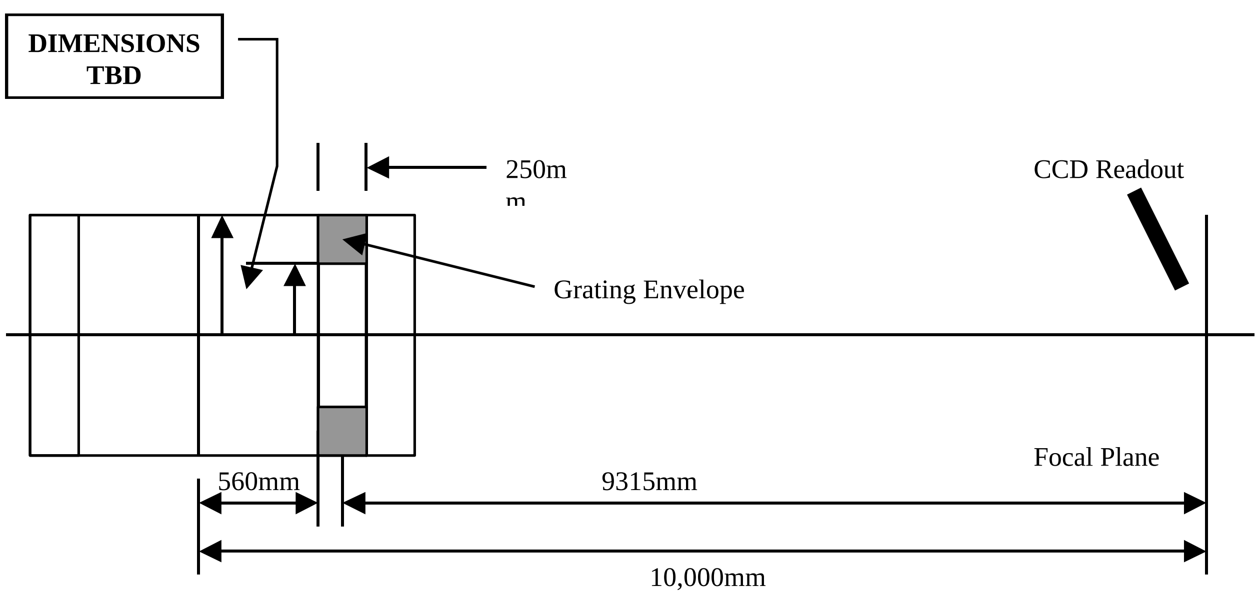


Figure 3- Grating Assembly Geometry and Envelope

2.1.5.2.2 Intercept Factor

The nominal grating intercept factor (percent of X-ray light intercepted and reflected off the gratings from the outer shells of the SXT optics which the gratings cover) shall be no more than 57%.

(source – Areas Flowdown)

2.1.5.2.3 Blockage Factor

The nominal grating blockage factor (percent of X-ray light which enters the grating but which does NOT exit the grating assembly due to internal blockages) shall be no more than 5%.

(source – Areas Flowdown)

2.1.5.2.4 Optical Performance

The optical performance of the RGA shall be compatible with the SXT/Grating/CCD telescope level performance requirements in Section 2.1.1.

2.1.5.2.5 Grating Efficiency

The grating efficiency is that fraction of the X-ray light entering the grating which is intercepted by the gratings and dispersed into the 0^{th}, 1^{st}, 2^{nd} and 3^{rd} order images. The nominal efficiencies are listed in Table XX, below.

E(KeV)	Effy(0)	Effy(-1)	Effy(-2)	Effy(-3)
0.277	TBD	0.20	0.00	0.01
0.523	TBD	0.29	0.03	0.01
1.253	TBD	0.10	0.29	0.07
1.497	TBD	0.02	0.21	0.13

Table 5 – Grating Efficiencies

(source – S. Kahn, Areas Flowdown)

2.1.5.2.6 Mass

The mass of the grating assembly shall not exceed 75kgm. This mass includes the grating elements, mounting structures and interface to the SXT.

2.1.5.2.7 Power

The grating assembly shall not require external power.

2.1.5.2.8 Thermal Environment

TBD.

2.1.5.2.9 Alignment Aids

TBD.

2.1.5.2.10 Interfaces

SXT and Post-Collimator.

2.1.5.3 CCD Detector Assembly

The SXT/Grating/CCD telescope uses a CCD detector assembly (including electronics) as its readout device.

2.1.5.3.1 Envelope and Geometry

The CCD detector unit shall be placed on the RGA Rowland circle near the focal plane of the SXT. The geometry of the Rowland circle for the RGA is shown in Figure 4. As shown in the figure, the Rowland circle includes the points A, the center of the grating array, and F, the telescope focus. The circle is nominally located within the satellite X-Y plane. Its' center is C and its' radius R. The line along the optical axis from A to F defines a chord of the circle. The center C is on a diameter from point A at an angle γ (the RGA graze angle) from the chord A-F. A *reflection* grating disperses its X-ray light along the Rowland circle, for this case in the Y direction. The X-ray light from the grating is focused at a point, FS in the figure, whose location in X and Y relative to the SXT focus is a function of field angle, wavelength and grating order.

Table 11 shows the dispersion distance in X and Y from the SXT focus for grating orders 0, 1, 2 and 3 for various wavelengths.

E(keV)	λ(ang)	0th Order		1st order		2nd order		3rd order	
		ΔY(mm)	ΔX(mm)	ΔY(mm)	ΔX(mm)	ΔY(mm)	ΔX(mm)	ΔY(mm)	ΔX(mm)
2.48	5	523.5	9.2	583.9	14.1	634.6	18.8	679.1	23.4
1.24	10	523.5	9.2	634.6	18.8	719.2	27.9	790.3	36.7
0.83	15	523.5	9.2	679.1	23.4	790.3	36.7	881.6	49.7
0.62	20	523.5	9.2	719.2	27.9	852.8	45.4	960.8	62.4
0.5	25	523.5	9.2	756.1	32.3	909.1	54.0	1031.7	75.0
0.41	30	523.5	9.2	790.3	36.7	960.8	62.4	1096.3	87.5
0.35	35	523.5	9.2	822.4	41.1	1008.8	70.9	1156.1	99.9
0.31	40	523.5	9.2	852.8	45.4	1053.8	79.2	1211.9	112.3
0.28	45	523.5	9.2	881.6	49.7	1096.3	87.5	1264.5	124.5
0.25	50	523.5	9.2	909.1	54.0	1136.6	95.8	1314.3	136.7

Table 6 – Grating Dispersion

Is this a requirement????, Yes at this level it is.

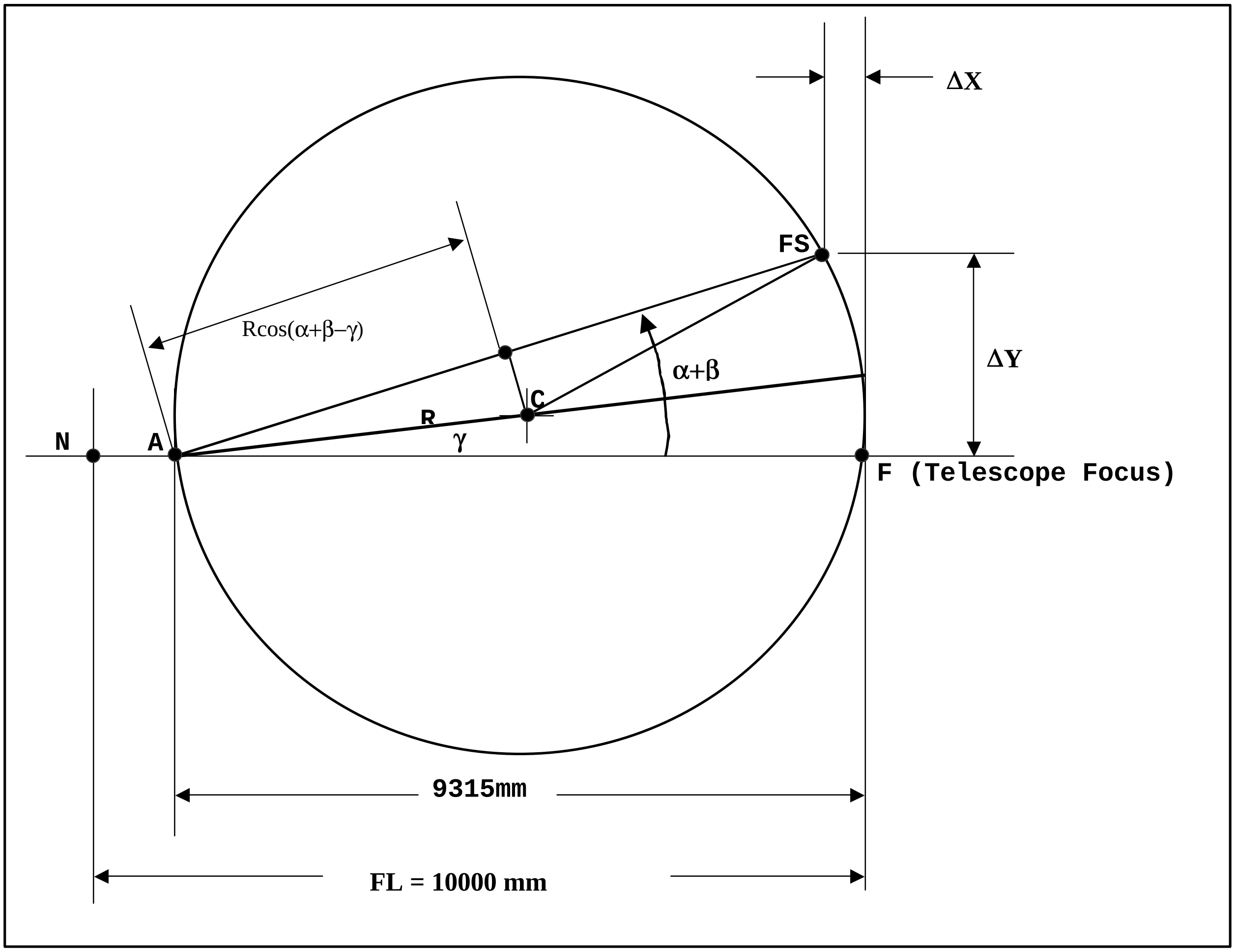
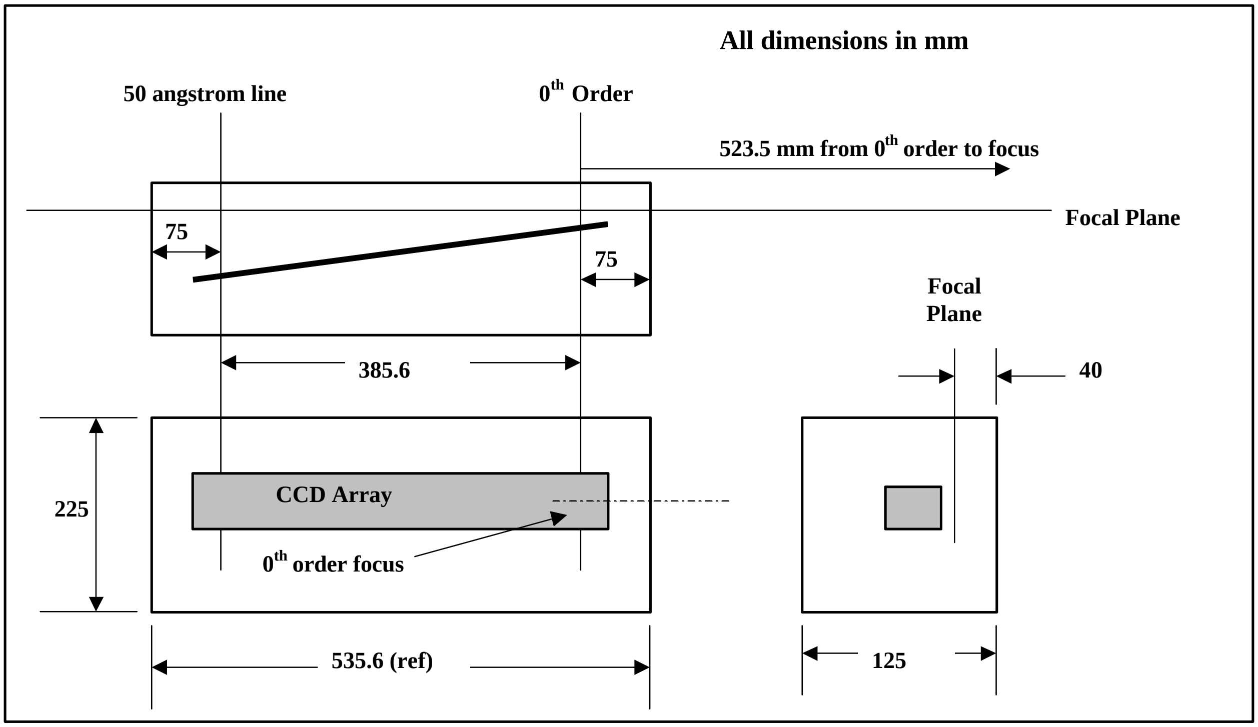


Figure 4 – Rowland Circle Geometry

The CCD detector unit shall capture the X-ray light from the 0^{th} orderplus all of the light within the required bandpass from the 1^{st} order. To accomplish this the CCD detector envelope and



positioning is as shown in Figure 5.

Figure 5 – CCD Detector Envelope and Positioning

2.1.5.3.2 CCD Pixel Size

The CCD pixel size in the dispersion (Y) direction shall be 5 arc-seconds (0.25mm) or smaller. The CCD pixel size in the cross-dispersion direction shall be TBD.

(Source – Flowdown from Resolution Error Budget)

2.1.5.3.3 Filter Transmission and Quantum Efficiency

E(KeV)	Filter Transmission	CCD Quantum Efficiency
0.277	0.30	0.90
0.523	0.59	0.97
1.253	0.94	0.99
1.497	0.96	0.99

Table 7 – CCD Filter Transmission and Quantum Efficiency

2.1.5.3.4 Background Rates

TBD.

2.1.5.3.5 CCD Energy Resolution

The energy resolution of the CCD chips will be used to help separate the various grating orders. This resolution shall be TBD.

2.1.5.3.6 Mass

The mass of the CCD Detector and associated electronics shall be less than 20 kgm.

2.1.5.3.7 Power

The total power consumed by the CCD detector assembly and associated electronics shall be less than 13.8 watts.

2.1.5.3.8 Visual Stray Light Rejection by Optical Blocking Filter

The rejection of stray visual light by the CCD detector optical blocking filter shall be at least $1x10^{-5}$, over the wavelength band of 3000 to 11000 angstroms. (Note: ACIS-S OBF was $5x10^{-5}$)

2.1.5.3.9 Interfaces

To be covered by ICD.

2.1.5.3.9.1 Mechanical

2.1.5.3.9.2 Thermal

2.1.5.3.9.3 Electrical

2.1.5.4 Calorimeter Assembly

The Calorimeter Assembly is used along with the SXT optics and a Cryogenic cooler to form the SXT/Calorimeter telescope. It includes the following sub-components:

1. An array of cooled X-ray detectors located at the focus of the SXT optics.
2. A final cooling stage for the detectors, such as an adiabatic demagnetization refrigerator (ADR)
3. Filters to block optical light.
4. Analog and digital electronics assemblies
5. Protective door assembly
6. Dewar and interface to cryo-cooler. **Dewar??**

2.1.5.4.1 Envelope and Geometry

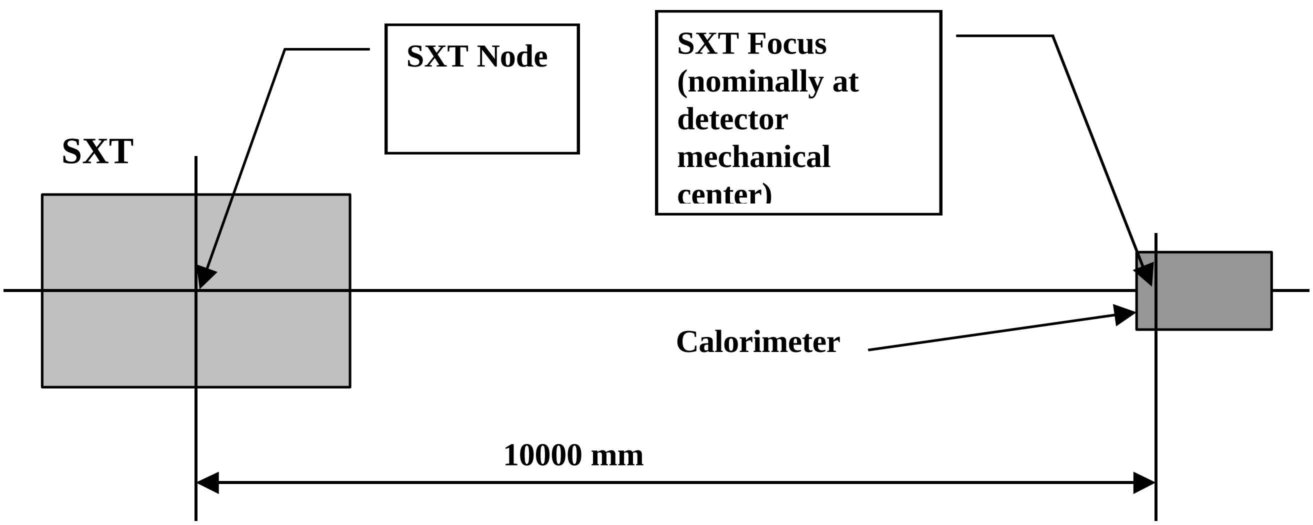


Figure 6 – Calorimeter Geometry

The Calorimeter detector assembly is mounted at the focus of the SXT optics as shown above in Figure 6.

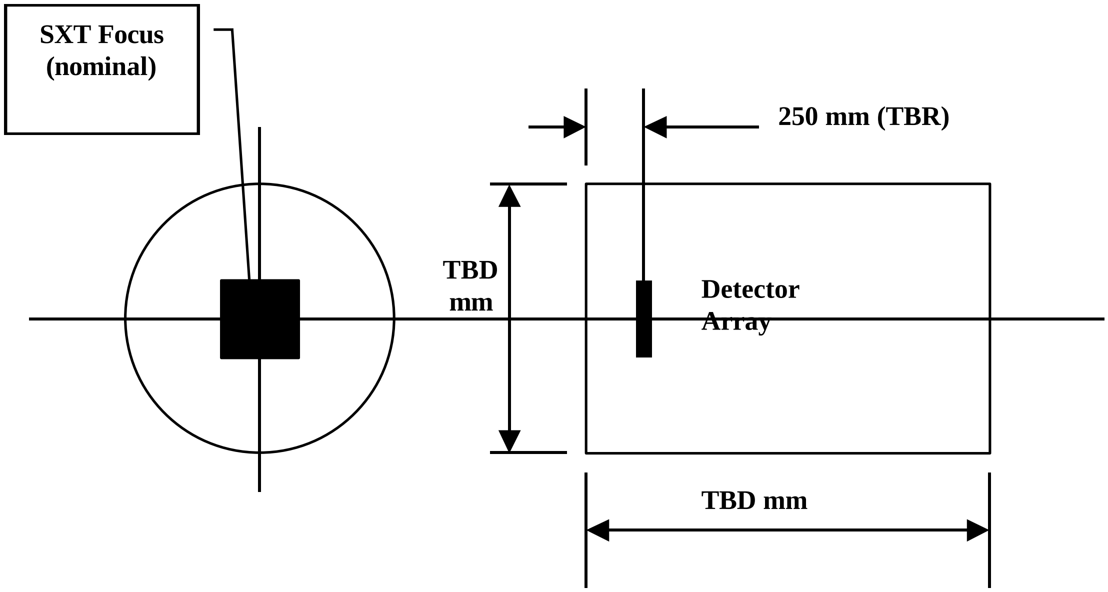


Figure 7 – Calorimeter Envelope

2.1.5.4.2 Energy Range

The calorimeter detectors shall operate over the energy range as specified in Table 12.

2.1.5.4.3 Energy resolution and Accuracy

The required spectral resolution of the Calorimeter detector is as shown in Table 3, Section 2.1.2.2. The spectral accuracy of the Calorimeter telescope shall 20% of the achieved spectral resolution.

2.1.5.4.4 Detector Field of View

The Calorimeter detector shall have a field of view of 2.5 arcmin (square) or larger (7.5 mm x 7.5 mm).

2.1.5.4.5 Detector Pixel Size

The Calorimeter pixel size shall be 5 arc-seconds (0.25mm) or smaller.

(Source—Angular resolution requirement)

2.1.5.4.6 Calorimeter Absorption and Filter Transmission

The Calorimeter shall have minimum quantum efficiency and filter transmission as listed in Table 9.

Energy (keV)	**Quantum Efficiency**	**Filter Transmission (PolyamideKevlar Mesh)**
0.277	1.00	0.16
0.523	1.00	0.44
1.253	1.00	0.87
1.497	1.00	0.91
4.510	0.99	0.98
6.403	0.94	0.99
8.048	0.79	0.99
9.713	0.61	0.99

Table 8 – Calorimeter Quantum Efficiency and Filter Transmission

2.1.5.4.7 Unrejected (telemetered)Background Rate

The Calorimeter detector shall have a maximum background rate of TBD cts/cm^2/sec/keV.

2.1.5.4.8 Mass

The mass of the Calorimeter detector assembly and associated electronics shall be no more than TBD kgm. This mass may be apportioned between the detector units and their associated electronics. This mass limit is intended to include the dewar but not the ADR.

2.1.5.4.9 Power

The calorimeter detector and associated electronics shall draw an average of no more than 100 watts and shall draw a maximum of TBD watts (peak) power.

2.1.5.4.10 Alignment Aids

TBD

2.1.5.4.11 Timing Precision and Resolution

The Calorimeter shall time tag each photon event to a precision of 10µsec relative to a timing signal sent from the spacecraft to the telescope electronics.

2.1.5.4.12 Count Rates

Total detector count rates of up to 10,000 counts per second, and per pixel count rates of 1,000 counts per second shall be observable without degradation of spectral resolution or timing precision.

2.1.5.4.13 Interfaces

Will be in ICD.

2.1.5.4.13.1Mechanical

2.1.5.4.13.2Electrical

2.1.5.4.13.3Thermal

2.1.5.5 Calorimeter Cryo-Cooler

2.1.5.6 HXT Optics Assembly

2.1.5.6.1 Optical Design

An HXT optics assembly consists of several sets of nested Wolter I (or conical approximation) shells with large focal ratios (focal length/radius), and therefore small graze angles. Each set of shells are held in a support structure, and several co-aligned and mounted sets make up an HXT optics assembly

2.1.5.6.2 Focal Length

The HXT optics assembly shall have a nominal focal length of 10m.

2.1.5.6.3 Field of View

The HXT optics shall have a minimum non-vignetted field of view diameter of 8 arcmin.

(source – Top Level Requirement 3.7)

2.1.5.6.4 Effective Area

The minimum effective area of the HXT optics assembly shall be as defined below. Note: These areas are 10% higher than the telescope level areas to account for the detector QE of 90%.

E(keV)	**Test Line**	**Area(cm^2) Per Satellite**
6.403[1]	Fe-Ka	425
8.048[1]	Cu-Ka	425
9.713[1]	Au-La	425
17.497	Mo-Ka	425
22.163	Ag-Ka	425
33.441	La-Ka	425
41.542	Eu-Ka	425
1) For Cross-calibration		

Table 9 – HXT Optics Assembly Effective Area

(source – Top Level Requirement 3.4)

2.1.5.6.5 Angular Resolution

The HXT optics shall have a Angular resolution of 50 arc-secs (HPD) or better.

(source – HXT Angular Resolution Error Budget)

2.1.5.6.6 Mass

The mass of the HXT optics assembly (per satellite) shall not exceed 85 kgm. This mass does not include structural mounting hardware needed to interface the HXT optics to the satellite.

2.1.5.6.7 Envelope

TBD.

2.1.5.6.8 Power

The HXT optics assembly shall require no more than 30 watts for thermal control.

2.1.5.6.9 Alignment Aids

2.1.5.6.10 Interfaces

2.1.5.6.10.1Mechanical

2.1.5.6.10.2Thermal

2.1.5.6.10.3Electrical

2.1.5.7 HXT Detector Assembly

The HXT Detector Assembly includes the high energy detectors, detector electronics, thermal control and mechanical and electrical interfaces to the satellite. It is mounted at the focus of the HXT optics Assembly. In this specification we will consider the detectors and associated electronics as two separate physical units, which work together as the HXT detector assembly.

2.1.5.7.1 Energy Range

The HXT detectors shall have an energy range as specified in Table 12.

2.1.5.7.2 Energy resolution

The HXTdetectorS shall have energy resolution ($\Delta E/E$) of 10% (or better) over the entire HXT band pass.

2.1.5.7.3 Detector Field of View

The HXT detector shall have a field of view of 8 arcmin (square) or larger.

2.1.5.7.4 Quantum Efficiency

The HXT detector shall have a quantum efficiency of 90% (or better) over the required detector energy range (including K escape events). **Need to define K escape events.**

2.1.5.7.5 Background Rate

The HXT detector shall have a maximum background rate of 2 x 10^{-4} cts/cm^2/sec/keV.

Source…?

2.1.5.7.6 Mass

The mass of the HXT detector assembly shall be no more than 33 kgm. This mass may be apportioned between the detector units and their associated electronics.

2.1.5.7.7 Envelope

TBD.

2.1.5.7.8 Alignment Aids

TBD.

2.1.5.7.9 Timing Precision and Resolution

The HXT Detector shall time tag each photon event to a precision of 10μsec relative to a timing signal distributed from the spacecraft to the telescope electronics.

(source – timing error budget)

2.1.5.7.10 Interfaces

2.1.5.7.10.1Mechanical

2.1.5.7.10.2Thermal

2.1.5.7.10.3Electrical

2.1.5.8 Optical Bench Assembly

2.1.5.8.1 Satellite Co-ordinate System

The satellite co-ordinate system (right handed) is depicted in Figure 1. The X axis is nominally the boresight axes of the telescopes. The Y axis is normal to the X axis and nominally aligned with the grating dispersion direction. The Z axis completes the right-handed system.

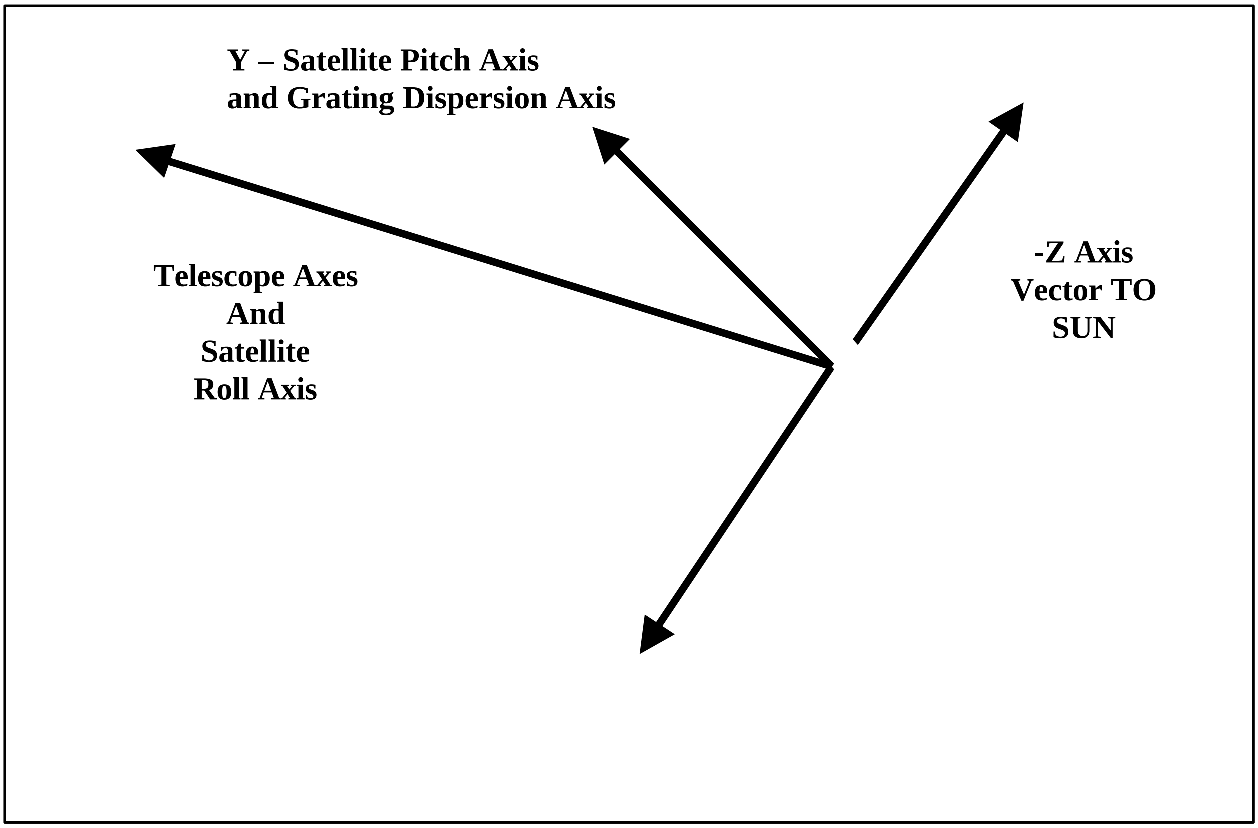


Figure 8 – Satellite Coordinate System Definition

2.1.5.8.2 OBA Definition

The Optical Bench Assembly (OBA) includes all of the components required to join the various X-ray optics to their respective X-ray detectors and to maintain alignment between the optics and detectors. It includes the support structure at the optics end of each Constellation-X satellite, support structure on the detector end of the satellite and the structure which joins the optics and detector end structures. Performance requirements for the OBA are derived mainly from the top level telescope optical requirements. Alignment and alignment stability, stray light protection, ghost image supression and protection from radiation are the major requirements derived from top level telescope performance. Other important requirements such as structural strength and stiffness, natural frequencies and interfaces are derived from other sources such as the launch vehicle environment, etc.

2.1.5.8.3 Alignment Overview

When the SXT or HXT optics are assembled an optical axis and a focus position will be established for each set of optics. In addition, when the reflection gratings are assembled with the SXT optics a dispersion direction is established. A complete telescope requires the integration of the focal plane detectors with the optics. In each Constellation-X satellite a single optical bench structure will be provided to carry all of the optics (SXT and HXT) at one end and all of the focal plane detectors at the other end, properly spaced apart and aligned. In some designs the optical bench may be deployable on-orbit and in others it may be of fixed length, not deployable. In either case there are two types of requirements, initial alignment and alignment stability. Initial alignment refers to the absolute angular and positional alignment (six degrees-of-freedom) of the optics to the detectors which is needed on-orbit, after launch and deployment of the optical bench, for proper operation of the telescopes. Alignment stability refers to the change in angular and positional alignment over various time scales such as the duration of an X-ray observation or the life of the entire mission.

In order to specify alignment and alignment stability tolerances, define a set of alignment reference axes for either the SXT or HXT optics such that:

1. The origin is at the node of the optics (i.e., in the paraboloid/hyperboloid interface plane at the geometric center of the shells).
2. The X axis is parallel to the optical axis and points away from focus.
3. The Y axis is in the direction of grating dispersion (for the SXT) or at a fixed orientation (HXT).
4. The focus is located at a known distance in the –X direction from the node.

Alignment of the focal plane detectors to the optics requires that:

1. The mechanical centers of the on-axis detectors are located at the respective foci of their optics (SXT/Calorimeter, HXT Optics/Detectors).
2. The CCD detector is aligned with its dispersion axis aligned with the SXT/Grating's dispersion axis and properly positioned on the Rowland circle.
3. The mechanical reference axes of the focal plane detectors are aligned with the optics reference axes.

2.1.5.8.4 Optics/Grating/CCD Alignment Requirements

The table below provides the requirements for alignment and alignment stability between the SXT Optics/Grating assembly and the CCD detector. These alignments must be achieved upon deployment of each satellite on-orbit and maintained throughout the life of the mission. The stability requirements stated must be maintained for the duration of an X-ray observation.

	δX	δY	δZ	θX	θY	θZ
	(mm)	(mm)	(mm)	(arcmin)	(arcmin)	(arcmin)
Alignment	0.50	0.50	0.50	1.00	1.00	1.00
Alignment Stability	0.20	0.10	0.20	0.50	0.50	0.50

Table 10 – SXT/Grating/CCD Alignment and Stability Requirements

Where

δX = deviation of focal plane instrument from optics in X (focus)
δY = deviation of focal plane instrument from optics in Y (dispersion axis)
δZ = deviation of focal plane instrument from optics in Z
θX = angular deviation of focal plane instrument from optics about X
θY = angular deviation of focal plane instrument from optics about Y
θZ = angular deviation of focal plane instrument from optics about Z

(The above alignment stability requirements are driven, in general, by the SXT/RGA/CCD system, with Y as the dispersion axis and a plate scale of about 50um per arcsec. The above table, changed from the previous rev, allocates about 2 arcsec, or 0.10 mm, for blur in the CCD line width caused by internal instability in Y. Backup will be provided in the Error Budget)
Is this assuming there is no fiducial system???
(source – SXT/Grating/CCD spectral resolution error budget)

2.1.5.8.5 SXT/Calorimeter Alignment Requirements

The table below provides the requirements for alignment and alignment stability between the SXT optics assembly and the calorimeter detector. These alignments must be achieved upon deployment of each satellite on-orbit and maintained throughout the life of the mission. The stability requirements stated must be maintained for the duration of an X-ray observation.

	δX	δY	δZ	θX	θY	θZ
	(mm)	(mm)	(mm)	(arcmin)	(arcmin)	(arcmin)
Absolute Alignment	0.50	0.50	0.50	1.00	1.00	1.00
Alignment Stability	0.20	0.20	0.20	0.50	0.50	0.50

Requirements are total deviation allowed. In the stability case the requirement is for total deviation over an observation.

Table 11 – SXT/Calorimeter Alignment and Stability Requirements

If all of the absolute alignment requirement error were applied simultaneously, would the image still be on the detector?

2.1.5.8.6 HXT Alignment Requirements

The table below provides the requirements for alignment and alignment stability between the HXT optics assemblies and their associated focal plane detectors. **Use of plural here versus singular for the SXT calorimeter is confusing. However, Ibet that these requirements are really for each optic to each detector and don't take into account assemblies of thruee…**These alignments must be achieved upon deployment of each satellite on-orbit and maintained throughout the life of the mission. The stability requirements stated must be maintained for the duration of an X-ray observation.

HXT Alignment and Stability Requirements(TBR)						
	δX	δY	δZ	θX	θY	θZ
	(mm)	(mm)	(mm)	(arcmin)	(arcmin)	(arcmin)
Alignment	3.00	2.00	2.00	1.00	1.00	1.00
Alignment Stability	1.00	0.50	0.50	0.50	0.50	0.50

(Need to clarify if these are total or +/-.)

Table 12 – HXT Optics/Detector Alignment and Stability Requirements

(source – TBD flowdown study)

2.1.5.8.7 Telescope Co-alignment Requirements

The boresight of each Constellation-X satellite shall be defined to be the average of all of the optical axes of all of the SXT's carried by that satellite. All of the HXT's carried that satellite shall have their optical axes aligned to the above defined satellite boresight within 1 arcmin. (Derived from 8 arcmin FOV of HXT's). **Is this why the HXT optic FOV is 11 arc sec??**

(source – TBD flowdown study)

2.1.5.8.8 Stray Light Requirements

2.1.5.8.8.1 Stray Light on CCD

Optical stray light over the band 3000 – 12000 angstroms at the entrance aperture of the CCD detector (in front of the CCD optical blocking filter) shall be limited to less than 1 x 10^{10} photons/sq.cm./sec.

Source--???

2.1.5.8.8.2 Stray Light on Calorimeter

TBD

2.1.5.8.8.3 Stray Light on HXT Detector

TBD

2.1.5.8.9 Cosmic X-ray Background

We wish to limit the cosmic X-ray background on the Calorimeter to 0.01 counts/sec over the SXT PSF. Since the SXT has a PSF of 15 arc-seconds (HPD), the approximate area of the PSF is 0.75 mm x 0.75 mm, or 0.5625 mm^2 or 0.005625 cm^2. The required count rate therefore becomes 0.01/0.005626 = 1.77 counts/cm^2/sec.

Protection from unfocussed X-rays shall be provided for each SXT. This protection shall be equivalent to 0.005" of tantalum over the solid angles outside the SXT field of view (AXAF Requirement, review for Constellation-X). This needs more explanation or a diagram.

2.2 Spacecraft Requirements

2.2.1 Pointing Control and Aspect Determination Subsystem (PCAD)

2.2.1.1 Pointing Requirements

The **SXT optical axis** is defined to be the line between the SXT node and the SXT focus, the SXT node being the point in the Paraboloid/Hyperboloid intersection plane at the center of the shells (zero radius). The SXT optical axis is defined during alignment of the optics. The line between the SXT node and the mechanical center of the calorimeter focal plane is the **SXT boresight.** During telescope assembly the SXT must be aligned such that its optical axis is coincident with the SXT boresight (within an alignment tolerance specified in the telescope sections). This alignment must also be preserved through launch and during on-orbit operations so that on-axis images will fall nearly in the center of the calorimeter.

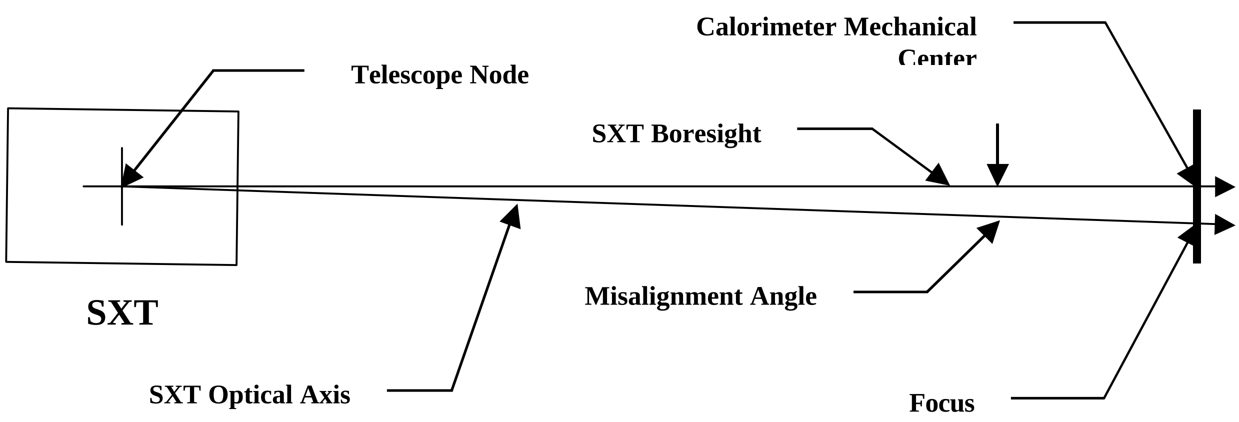


Figure 9 – SXT Boresight Definition

Each HXT will also have its own optical and mechanical axes which are defined in a manner similar to that for the SXT. During assembly of each Constellation-X satellite the HXT optics are aligned with the HXT detectors. In addition, the HXT axes must be aligned with the **SXT boresight**, so that the HXT's will be on-target when the SXT is. **Redundant**

In addition to the telescope level alignments and co-alignment, the satellites' star tracker must be aligned so that its pointing axis is aligned (within some tolerance) with the SXT boresight. On-orbit calibration of the SXT boresight to the star tracker allows us to point via the star tracker and have the target images on the detectors.

2.2.1.1.1 Nominal Pointing Direction

Each Constellation-X satellite shall be designed to point at targets whose pointing direction (satellite to target) is nearly normal to the sun vector (vector from the sun to the satellite). In the nominal pointing case the satellite's –Z axis is aligned with the sun vector (see Figure 1).

2.2.1.1.2 Yaw Requirement

From the nominal pointing case, the satellite shall be capable of yawing 360 degrees about its Z axis (except for pointing restrictions due to earth/moon avoidance) to point at targets whose pointing direction is normal to the sun vector.

2.2.1.1.3 Pitch Requirement

Additionally, the satellite shall be capable of observing targets within +/-20 degrees from the plane normal to the sun vector, which requires a sun pitch angle capability of +/- 20 degrees (i. e., the sun vector is in the X-Z plane within +/- 20 degrees of the –Z axis.

2.2.1.1.4 Off-Nominal Roll Requirement

The configuration described above in section 2.3.1.1.3, with the sun vector in the X-Z plane, is defined as the "nominal roll angle" configuration. From this nominal roll angle configuration, the satellite must also be capable of rolling about its own X axis by +/- 20 degrees. This situation defined as an "**off-nominal roll**". In this situation, the sun vector is within +/- 20 drees of theX-Z plane.

Note: The above defined yaw, pitch and roll requirements were derived so as to meet the sky viewing requirements in Section 3.17 of the top level requirements while in the L_2 orbit.. The roll requirement allows resolution of multiple targets in the grating spectra by placing the images of these targets at different Z positions in the focal plane, and hence having the spectra separated it the Z direction in the CCD readout.

2.2.1.1.5 Safe Pointing Constraints

The SXT boresight axis shall, under any condition (including target-to-target slew maneuvers), be pointed no closer than 45 degrees from the Sun and 30 degrees from the sunlit Earth or Moon *(driven by aspect camera, HRC and ACIS on AXAF).*

2.2.1.1.6 Viewing of Solar System Objects

Constellation-X shall have the capability to observe solar system objects (planets, comets, etc.). This requirement shall be implemented using a "point-and-shoot" technique in which a series of inertially fixed pointings separated by slews to the next pointing direction are commanded in the daily load. "Tracking" of objects shall NOT be required.

2.2.1.2 Pointing Control Accuracy

The SXT boresight axis shall be pointed at a target defined by an absolute right ascension and declination and it shall be kept to within a radius of 30 arcsec(3σ) of this target for the duration of the observation.

(Note: This requirement is driven by the need to keep the target image centered within the calorimeter field-of-view, which is 150 arc-seconds.)

2.2.1.3 Roll Control Accuracy

The roll angle for an observation shall be specified along with the absolute right ascension and declination. The roll angle shall be shall be controlled to within 60 arcsec(3σ) of the commanded roll angle for the duration of an X-ray observation.

2.2.1.4 Aspect Solution Accuracy

Data from the onboard satellite pointing control system (star tracker data, gyro data, etc.) shall be provided to the ground data analysis system for the purpose of developing an **aspect solution** for each observation. The aspect solution is defined as the best post-facto (after an observation has been completed and using all available data) estimate of the SXT boresight pointing direction, relative to selected guide stars in the star tracker(s), and the satellite roll angle. The aspect solution is a function of time and is derived on the ground for all times during each X-ray observation. The data provided shall enable the calculation of an aspect solution accurate to 5 arcseconds (3σ) in the pointing direction. **Pointing direction of what? If stability of "only" 30 arc sec between optics and detector are required—we need to define what exactly needs to known to 5 arc sec—because it won't necessarily be the same for the optics and the detector.**

(Celestial co-ordinate top level requirement, image re-construction error budget allocation)

Note: The aspect solution is needed to re-construct images on calorimeter and line readouts on CCD and also to locate these images on the sky. The above requirement provides for both a celestial location accuracy of 5 arcseconds (3 sigma) and for image reconstruction errors of 5 *arcseconds (again 3 sigma basis). This requirement provides a small image degradation as compared with the 15 arcseconds HPD SXT image resolution.*

2.2.1.5 Roll Knowledge Accuracy

The data provided from the satellite shall enable the calculation of roll angle with an accuracy of 30 arcseconds (3σ) TBR.

2.2.1.6 Target Change Time

Each satellite shall be capable of changing observation targets within a total time of 60 minutes. This time includes the time needed to slew between any pair of targets, acquire the guide stars and settle into stable pointing.

(top level requirement 3.15)

2.2.1.7 Pointing Stability

During an X-ray observation the rate of change of the satellite pointing direction shall be no greater than 1 arcsecond in any two second interval.

Note: This requirement is driven in two ways. First, typical star tracker tracking rates (for full accuracy) require this low rate. Second, we need the motion of the satellite to be smaller than one CCD pixel over a CCD readout time so that during image reconstruction we can properly shift each event by the proper angle as provided by the aspect solution. For example, if the pointing direction moved 10 pixels in one readout frame then we do not know where that pixel was when the event occurred.

2.2.1.8 Roll Stability

During an X-ray observation the rate of change of the satellite roll angle shall be no greater than TBD arcseconds in any one second interval.

2.2.1.9 Jitter

We expect to use the star trackers on the satellite to correct photon positions for measurable motion of the pointing direction over an X-ray observation time of up to 48 hours. However, there will be some effects which are not measurable due to either their high frequency (compared with star tracker sample rates) or due to the fact that they are non-rigid body effects which the on-board star trackers (or fiducial system if there is one) cannot sense. The result of these effects is an uncorrectable image broadening, and we desire to limit this effect to a two arcsecond degradation in overall image quality. The requirement may be stated as follows:

The broadening of a re-constructed X-ray image due uncorrected rigid and non-rigid body motion, for frequencies above TBD Hz., shall be limited to 2 arcseconds RMS radius.

Note: This requirement is equivalent to stating that if we had a perfect mirror and infinite resolution focal plane detector, then the RMS radius of the imaged photons would be 2 arcsecseconds, entirely due to these uncorrected motions.

(Angular resolution error budget)

2.2.2 Command and Data Handling (C&DH) Subsystem Requirements

The C&DH subsystem provides the following capabilities:

1. Provide precise spacecraft timing reference signal to spacecraft subsystems.
2. Provide a spacecraft time reference in the real-time telemetry stream for the purpose of correlation with UTC on the ground
3. Support spacecraft ranging by routing the ranging signal back to the appropriate transmitter
4. Receive Uplink Commands, decode, validate and distribute to destination subsystems
5. Provide downlink telemetry of housekeeping data by collecting from various subsystems, formatting, encoding and distributing to appropriate transmitter
6. Collect asynchronous science data from three science instruments and store in temporary science data buffers
7. Create downlink science/housekeeping telemetry stream in CCSDS format, at fixed frame rate, from combination of housekeeping and science data and store in telemetry buffer (i.e., Solid State Recorder).
8. Provide downlink telemetry of science/housekeeping data at a variety of commandable bit rates, reading data out from the SSR, formatting, encoding and distributing to appropriate transmitter
9. Provide spacecraft safing functions as specified

2.2.2.1 Spacecraft Clock and Internal Timing Reference

The spacecraft C&DH subsystem shall maintain an on-board clock with a drift rate less than 10^{-9} parts per day. This clock shall have a range of at least 2^{32} seconds and a resolution of 1μ second or better.

Timing reference signals derived from the spacecraft clock shall be provided to each science instrument. A high time resolution pulse train, accurate to within +/- 1μ seconds at the science instrument interface, shall be provided to each science instrument. In addition, a major telemetry frame synch pulse and frame identifier word shall be provided to each science instrument at the start of each major telemetry frame. (The science instruments will time tag each event using the major frame number and pulse count to the event, relative to the major frame synch)

2.2.2.2 Ground Timing Reference

Since event data from multiple satellites will be combined to produce a single observation, event times (referenced to the spacecraft clock) must ultimately be referenced to some absolute time, such as UTC. To do this, the spacecraft must be correlated to UTC.

Therefore, the C&DH subsystem shall provide a timing reference signal (either self-generated or stimulated by the ground uplink data stream) in the real-time housekeeping telemetry stream. The spacecraft clock reading at the time of generation of this signal shall be encoded in telemetry. The time between generation of the on-board timing signal and downlink from the spacecraft (at the antenna) shall be calibrated to within an error of +/-1µ seconds.

2.2.2.3 Spacecraft Ranging Support

The spacecraft shall provide support for ranging by routing the uplinked ranging signal to the transmitter for mixing with the telemetry signal and re-transmission to the ground.

2.2.2.4 Uplink Command Processing

The C&DH subsystem shall provide uplink command capability, using CCSDS protocols, at an uplink rate of 2kbps (kilo bits per second) using two diametrically mounted S-band omni antennas to provide complete spherical field of view. Both uplink receivers shall remain active at all times. Received commands are checked by the C&DH system for validity and then routed to the target subsystem for processing.

2.2.2.5 Real Time Downlink of Housekeeping Telemetry

The C&DH subsystem shall provide downlink telemetry of housekeeping data at a rate of 2kbps (8kbps as a goal) by collecting data from various subsystems (including each science instrument), formatting, encoding and distributing to appropriate S-band transponder (one of two, transmitter switchable) for transmission to the ground in real-time.

2.2.2.6 Science Data Rates, Data Capture and Buffering

The C&DH subsystem shall provide a data interface and temporary data storage for each of the three science instruments on the spacecraft. Science data packets shall be asynchronously transferred from the science instrument to the C&DH subsystem upon request of the science instrument. The average science data rate from all three instruments shall be 48kbps. The peak science data rate from all three instruments shall be 1365kbps.

The C&DH subsystem shall provide buffer storage capacity for one day's worth of science data at the peak data rate, or approximately 120 Gbits (15 Gbytes).

2.2.2.7 Science/Housekeeping Telemetry Stream

The C&DH subsystem shall create downlink science/housekeeping telemetry stream in CCSDS format, at fixed frame rate, from combination of housekeeping and science data and store in a solid state telemetry buffer. The bit rate shall be 50kbps (48kbps science and 2 kbps housekeeping) with a goal of 56 kbps (48kbps science and 8 kbps housekeeping).

The C&DH subsystem shall provide storage for 2 days worth of telemetry (~9Gbits or 1125Mbytes).

2.2.2.8 Downlink of Science/Housekeeping Telemetry Stream

The C&DH subsystem shall provide an X-band downlink of the stored science/housekeeping data at a variety of commandable bit rates, reading data out from stored memory, formatting, encoding and distributing to X-band transmitter. The maximum downlink telemetry rate shall be 1700kbps.

2.2.2.9 Safing Functions

TBD

2.2.3 Propulsion Subsystem

2.2.4 Power Subsystem

2.2.5 Thermal Subsystem

2.2.6 Flight Software

2.2.7 Safe Mode Requirements

3. GROUND SEGMENT

4. LAUNCH SEGMENT

5. ERROR BUDGETS

5.1 SXT/Grating/CCD Spectral Resolution Error Budget

5.2 SXT/Grating/CCD Wavelength Accuracy Error Budget

5.3 Spacecraft Pointing Control Error Budget

5.4 Image Reconstruction Error Budget

5.5 Celestial Location Error Budget

5.6 SXT/Calorimeter Angular Resolution Error Budget

5.7 SXT Effective Area Budget

5.8 Calorimeter Spectral Resolution Error Budget

5.9 Calorimeter Spectral Accuracy Error Budget

5.10 Timing Accuracy Error Budget

5.11 Stray Light Error Budget

5.12 Data Latency Error Budget

5.13 Photometric Accuracy Error Budget

How about SXT/grating/CCD alignment budget, SXT/calorimeter alignment budget, and HXT alignment budget?

Appendix A – Working Assumptions

SXT Focal Length: 10.0m
Plate Scale: 48.5υm/arcsec
Wavelength Scale(avg): 1.1 angstroms/mm , 909υm/angstrom
Relationship between plate scale and wavelength scale: 18.7 arcsec/angstrom
CCD Pixel size: 48υm wide x 192υm high (1 arcsec wide x 4 arcsec high
Calorimeter Focal plane: 5 arcsec x 5 arcsec pixels, 30 x 30 array, 2.5 arcmin square FOV
HXT Pixel size: 50υm square
HXT FOV: 8 arcmin square